



American Automobile Manufacturers Association

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JAN 30 1995

FEDERAL COMMUNICATIONS COMMISSION
OFFICE OF SECRETARY

January 30, 1995

Mr. William F. Caton, Secretary
Federal Communications Commission
Washington, D.C. 20554

DOCKET FILE COPY ORIGINAL

Re: Comments of American Automobile Manufacturers Association on Amendment of Parts 2 and 15 of the Commission's Rules to Permit Use of Radio Frequencies Above 40 GHz for New Radio Applications (ET Docket No 94-124, RM-8308)

The attached American Automobile Manufacturers Association (AAMA) comments on the subject docket, reflect broad based agreement, and a common understanding, of the American automobile manufacturers regarding the need for radar RF spectrum allocations. The comments are supplemental to those comments filed by the Association on RM-8308, February 1994. Because manufacturers anticipate offering vehicular radar systems in the near future, AAMA requests the Commission continue their expeditious effort for frequency allocation.

The AAMA comments are intended to provide the Commission essential, and more specific, supplemental information about the needs of the American automobile manufacturers on this subject based on issues covered in the FCC Notice. As such, these comments provide a more complete record for agency decision-making.

AAMA will also serve the attached comments on all parties in this proceeding, who

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will then have the opportunity to address any issues raised.

Accordingly, AAMA urges the Commission to accept the attached comments and supporting rationale that explain the spectrum, power, test, and band usage for vehicular radar.

AAMA appreciates the expeditious manner the Commission has acted on this important issue and we expect the Commission and its staff will continue with frequency allocation on a non interrupted basis.

Please contact Ron Wasko of my staff at (313) 871-6335 if you require additional information concerning any aspects of the AAMA comments.

Very truly yours,

A handwritten signature in black ink, appearing to read "Vann H. Wilber", with a long horizontal flourish extending to the right.

Vann H. Wilber, Director
Vehicle Safety and International

Attachment

cc: Richard Engleman, Chief, Technical Standards Branch
Julius Knapp, Chief, Authorization and Evaluation Div.
John Reed, Engineer, Technical Standards Branch
Thomas Stanley, Chief Engineer, Engineering and Tech.
William Torak, Office of Engineering and Tech.
David R. Siddall, Office of Engineering and Tech.

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Before the
Federal Communications Commission
Washington, D.C. 20554

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FEDERAL COMMUNICATIONS COMMISSION
OFFICE OF SECRETARY

FCC Docket No. 94-124, RM-8308

Amendment of Parts 2 and 15)
of the Commission's Rules to)
Permit Use of Radio Frequencies)
Above 40 GHz for New Radio)
Applications)

ET Docket No. 94-124
RM-8308

DOCKET FILE COPY ORIGINAL

Comments of:

American Automobile Manufacturers Association, Inc.
7430 Second Avenue, Suite 300
Detroit, MI 48202

Respectfully submitted,

AMERICAN AUTOMOBILE
MANUFACTURERS ASSOCIATION

Date

January 30, 1995

by



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SUMMARY

A summary of the major issues addressed in the Association's comments are:

1. AAMA requests 152 - 154 GHz band for automotive radar.
AAMA relinquishes its request for 139 -140 GHz band for automotive radar.

This requested change would permit manufacturers to double the 77 GHz frequency modules, (notice grants 76 - 77 GHz band for automotive radar) to 152 - 154 GHz which is expected to result in faster, lower cost modules and improved time to availability. Adding 1 GHz to the band at 153 GHz band is needed for expansion of radar performance capability, e.g. longer ranges, tighter angular resolution, and tighter range resolution.
2. We concur with the Commission that the expected general use of automotive radar systems for the public good negates auctioning these bands as they will not generate compensation from subscribers. The radar devices will benefit the public and the social good of the country will be enhanced.
3. AAMA supports the fact that when and if the Commission permits other users in the automotive radar bands, careful coordination be undertaken to ensure compatibility between all systems operating in the bands.
4. Test procedures for defining the performance of devices above 40 GHz are needed.
5. Maximum power levels needed for future automotive radar applications are recommend by AAMA as shown in table on the following page. AAMA also details maximum in-band and out-of band spurious peak power levels.

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Before the
Federal Communications Commission
Washington, D.C. 20554

FEDERAL COMMUNICATIONS COMMISSION
OFFICE OF SECRETARY

In the matter of:

Amendment of Parts 2 and 15
of the Commission's Rules to
Permit Use of Radio Frequencies
Above 40 GHz for New Radio
Applications

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ET Docket No. 94-124
RM-8308

**Comments of American Automobile Manufacturers Association, Inc. --
Re: ET Docket No. 94-124; RM-8308**

1.0 INTRODUCTION

The American Automobile Manufacturers Association (AAMA), whose members are Chrysler Corporation, Ford Motor Company, and General Motors Corporation, submits these comments for vehicle radar system spectrum needs. These comments result from the AAMA Intelligent Vehicle Highway System (IVHS) Electromagnetic Spectrum Task Group reviewing the FCC Notice of Proposed Rule Making, Docket 94-124. The AAMA task group was formed by AAMA in March of 1993 to investigate spectrum needs for IVHS applications. Automotive radar systems are close to commercial realization, and the development of marketable systems for use by the public depends on millimeter wave transmissions for which specifications need to be defined. Therefore a regulatory approach with respect to use of millimeter wave spectrum must be adopted to accommodate the emerging vehicle radar

technologies. The AAMA comments on the inclusion of new bands for automotive radar applications should not preclude the use of previously approved frequency bands for such automotive radar applications below or within the millimeter wave region.

The deployment of vehicle radar systems is in the public interest due to expected impact on driver convenience, motor vehicle safety, reduced traffic congestion (thus reducing fuel consumption), and reduced insurance costs. Forward-looking, side-looking, and rear-looking radar systems are currently envisioned.

Forward-looking systems include such applications as radar cruise control, collision warning, and collision avoidance. Radar cruise control systems improve the performance of conventional speed control systems by automatically adjusting vehicle speed based on traffic ahead. In a typical collision warning system, objects forward of the vehicle are detected and their trajectory determined. The object's trajectory is compared to that of the vehicle and the driver is warned of an impending collision. In a collision avoidance system, the control of the vehicle (e.g., braking) could be automatically affected in response to an impending collision.

Forward-looking systems will require high resolution (angular and range) and accuracy. The angular resolution of a radar depends on the antenna aperture and transmitter frequency. Specifically, a fine angular resolution requires either a large aperture or a high frequency. Good range resolution depends on having a large signal bandwidth.

Packaging of the sensor and other components within the vehicle limits the aperture size of the antenna. For forward looking radar, the antenna would almost invariably be located in the grille and must, therefore, be small in size due to airflow and styling considerations and other vehicular regulatory requirements. Consequently, high frequency transmissions are required to obtain sufficient angular resolution.

Side-looking and rear-looking radar systems will provide obstacle detection by monitoring objects in areas where the driver may have reduced direct visibility. Visual displays and audible tones may be used to alert the driver to detected objects. These systems will typically employ lower angular resolution than forward-looking systems and will be easier to package on the vehicle since smaller antenna apertures can be used at these lower frequencies.

Vehicular radar will incorporate existing radar technologies and will utilize many well known and understood techniques. Many different types of modulation and waveform schemes will be possible including signal matching and spread spectrum techniques. The ability of systems using these modulation techniques to withstand co-channel and adjacent channel interference is known (see Section 2.3 of the AAMA comments submitted February 1994). Thus, each individual radar system would respond only to its own transmitted signals with other similar or identical systems in its vicinity or even in its direct line of sight.

Currently, manufacturers are developing these types of radar devices for use on motor vehicles for driver comfort and convenience as well as safety.

2.0 SPECIFIC COMMENTS TO DOCKET 94-124

Comments to the Notice are referenced by specific topic providing technical data. AAMA has not developed nor is it submitting comments on all paragraphs within the Notice of proposed rulemaking. AAMA members may individually submit additional comments to the Notice.

Specific comments on spectrum needs and related issues addressed by the Notice follow:

Proposed Frequency Bands and Bandwidth:

AAMA requests that the FCC permit the following change to the proposed frequency allocation bands.

139.5 to 140.0 GHz - General Unlicensed

139.0 to 139.50 GHz - Licensed

152.0 to 154.0 GHz - Automotive Radar

AAMA recognizes the Commission's concern over allowing multiple requests for the same application. AAMA's original comments requested allocation of two bands greater than 100 GHz to accommodate higher resolution and longer range systems that would enhance collision warning and collision avoidance applications. Based on the Commission's concern over band allocation, AAMA agrees with the recommendation to eliminate one of the high frequency bands and requests that the Commission eliminate the 139.5 GHz band and assign the 153.0 GHz band as the designated automotive radar band.

This AAMA request would trade the FCC proposed allocation of 139-140 GHz for Automotive Radar with the FCC proposed allocation of the 153 GHz band for future licensed and unlicensed use and increase the allocated bandwidth of the high frequency automotive radar band to 2 GHz.

The request to allocate the 153 GHz band to automotive radar and to increase the operating bandwidth is based on the need to allow for continued expansion of radar performance capability while minimizing hardware development costs and timing as well as recurring costs of the product. One low cost method of reaching a band above 100 GHz is to double the 76.5 GHz band.

Future collision warning/collision avoidance systems will be required to

operate at longer ranges, tighter angular resolution, and tighter range resolution than systems currently in evaluation today. These improved performance requirements are driven by the need to track targets through curves, provide adequate time for complete braking at limited access highway speeds, and provide for highway convoy considerations currently being defined at ITS America and certain government agencies. It is anticipated that a modulation bandwidth as much as 1 GHz will be required.

Based on the allocation of the 76.5 GHz band for automotive radar, the most straight forward way to expand into the greater than 100 GHz range of operation is to use the same basic millimeter wave components developed for the 76.5 GHz band and to frequency double the oscillator output. Placing a tighter restriction on percentage bandwidth at 153 GHz, however, does not allow direct multiplication of the output frequency of systems operating in the 76.5 GHz range unless greater restriction on center frequency is applied. Tightening of the center frequency requirements at 76.5 GHz prior to multiplication will result in a significantly higher recurring cost to the consumer. Therefore, AAMA submits that a 2 GHz bandwidth is necessary for the 153 GHz band.

The impact of percentage bandwidth on recurring cost is demonstrated by experience with near obstacle detection systems operating at X-band. The following data show the relationship of recurring cost to percentage bandwidth allowed for center frequency variation based on actual production data for X-band and the corresponding projected impact on millimeter wave systems.¹ These normalized costs are provided based on manufacturers best current estimates.

¹ Letter from William J. Chundrlik, Jr. of General Motors to Dr. Michael J. Marcus, Assistant Chief, FCC Office of Engineering and Technology dated January 19, 1995.

% Bandwidth	Module Cost Impact X-band Actual	Module Cost Impact W-band Projected
0.5%	+26%	+49%
1.0%	+10%	+20%
1.5%	Baseline	Baseline
2.0%	-7%	-9%

Table 1. Percentage Bandwidth versus Cost

The data shown above are normalized to a 1.5% bandwidth and are based on component cost, production test, and production module yield for the center frequency parameter only. The unit cost includes temperature testing of the units on a 100% basis for center frequency to comply with the FCC frequency and temperature specifications. The projected W-band costs assume the yield losses taken at the component level to be constant, and reflects the yield loss impact of the inherently more costly millimeter wave components.

The data shown above are based on center frequency variation for a low modulation bandwidth system. Final determination of the cost impact must include the required modulation bandwidth. If a system requires 300 MHz operating modulation bandwidth at 76.5 GHz, the allowed effective percent bandwidth variation of center frequency is reduced to:

$$[(1000 \text{ MHz} - 300 \text{ MHz}) / 76.5 \text{ GHz}] \times 100\% = 0.915\%.$$

Frequency multiplication of this waveform provides the anticipated 600 MHz bandwidth of future systems operating in the 153 GHz band. Neglecting the higher costs for 153 GHz band, conservative estimates for the cost impact

table for higher modulation bandwidth at 153 GHz become:

Modulation Bandwidth	FCC Allocated % Bandwidth 153 GHz	FCC Effective % Bandwidth 153 GHz	Module Cost Impact W-band Projected 1 GHz BW	Module Cost Impact W-band Projected 2 GHz BW
200 MHz	0.65 %	0.52 %	+47 %	+14 %
400 MHz	0.65 %	0.39 %	+65 %	+27 %
600 MHz	0.65 %	0.26 %	+95 %	+48 %

Table 2. Modulation Bandwidth and Module Cost Impact

The non-recurring engineering costs and schedule impact for redesigning circuits to the 139.5 GHz versus designing the appropriate frequency multiplier and receiver front end circuits for the 153 GHz band cannot be quantified at this time, but it is a certainty that for those systems operating at 76.5 GHz, the cost and schedule impact is significantly higher than the direct frequency multiplication approach. It has been shown that the recurring cost impact to the consumer is greatly reduced by allowing a 2 GHz operating band at 152-154 GHz range. Consumer acceptance of these products and the corresponding collision mitigation will be a direct function of the cost of the product to the consumer. Increasing the allowed bandwidth to 2 GHz for frequencies greater than 100 GHz would improve the time to availability and the affordability of these products to the consumer.

Currently, there are at least several companies known to be working in IVHS system development: Chrysler, Ford , GM, TRW, Millitech Corporation, Alpha, and VORAD. Additional companies not known to AAMA may also be developing systems. After a rulemaking, the number of companies entering the market may increase. European developers would be expected to enter the U.S. market. Although the number of devices operating within the prescribed bands cannot be quantified at this time, as the market for such devices increases, the number is expected to be large (millions). Therefore, special care must be taken in estimating bandwidth for multiple users. Various system safety related requirements, such as interference, must not be sacrificed.

A forward looking radar system's bandwidth requirements impact many system design parameters, both for hardware and signal processing. Parameters such as range resolution, Low Probability of Interference (LPI), waveform, target discrimination, multi-path, as well as others, are related to the transmission bandwidth. Also, the type of system (collision avoidance, automatic cruise control, lane changing, or back-up aid) will have different parameter requirements.

Typical systems being developed to date require operating bands of 200 to 500 MHz typical, with some requiring 1 GHz. These bandwidths are required partly due to waveform requirements for spread spectrum techniques. Two typical spread spectrum waveforms are shown in Figure 1. Both types of transmissions are what is known as pulse compression techniques. Pulse compression allows the transmitter to execute a wide band signal over time while the receiver remains narrow band; thus compressing the wide band information into the receiver's narrow band. A system's signal to noise ratio (SNR) is inversely proportional to receiver bandwidth. Therefore, a narrow receiver bandwidth will increase the SNR and thus reduce the required

transmit power. The transmitted signal bandwidth, however, needs to be wide to maximize the information obtained from the return signals. More information can be extracted from the return signals when a wider transmitter bandwidth is used.

Range resolution (dr) of a system is related to the waveform bandwidth by:

$$dr = c / 2B$$

c = the speed of light and

B = the waveform bandwidth

Range resolution (dr) refers to slant range resolution, e.g. in the radial direction. Therefore, a high B , yielding greater resolution, is crucial in obtaining information for the target location. For automatic cruise control systems, typical resolution requirements are 0.5 m to 2 m which translates into a B of 75 to 300 MHz, see Figure 2.

Forward looking collision warning systems require even greater resolution. These systems essentially need to form images. Greater resolution results in more detailed images. The images formed must be able to resolve multiple targets of typically less than one meter from each other. Ideally, these systems require finer resolution but may be limited by processing through-put.

The resolution capability is also used in discrimination where the signal processing must separate types of targets such as a highway maintenance cone in the road and a stationary bicycle. For example, if the system's resolution was only two meters, both targets would be both approximately two meters in depth. However, with a dr capability of 0.25 m, the highway maintenance cone would have an observable depth of 0.25 m and the bicycle of 1.75 m, thereby providing discrimination.

For collision warning systems, two dimensional target trajectory information must be calculated. Target trajectory versus radar vehicle trajectory is a safety-critical issue and requires good dr, range precision, and wide bandwidth. The trajectory comparisons by the radar system will produce warning information for the driver.

Target trajectory data can also be used to note road curves and can assist in road edge detection. Narrow band transmitters would be unable to perform trajectory functions. As an example, the standard lane width is 3.6 m. To locate the edge of the road to an accuracy of 1/10th the lane width, a resolution of 0.36 m is required. Thus, a minimum bandwidth of 416 MHz, neglecting drift and side lobes, is required.

Lane changing and backup systems have a shorter range of interest, typically less than 0.25 m to 5 m. If a spread spectrum waveform were used, dr may need to be 0.25 m or better; this equates to bandwidth of greater than 500 MHz.

In considering necessary bandwidth, guard bands must be added into the transmit bandwidth requirement to account for short term and long term frequency drift (aging) as well as modulation side lobes. Drift due to aging is an important factor in an automobile product. Automobile manufacturers strive for quality and reliability. A desirable Mean Time Between Failure (MTBF) for an automobile radar system would be 50,000 to 100,000 miles; periodic radar "tune-ups" are not economically feasible.

Transmitter bandwidth requirements for initial radar systems is 300 to 500 MHz. As systems mature, (with expected increases in range capability,

resolution, target discrimination, etc.), bandwidths greater than 1 GHz and up to 2 GHz are needed to account for aging and other effects already discussed (e.g. drift, modulation, side bands). Bandwidths of 1 GHz, for bands below 100 GHz and 2 GHz, for bands above 100 GHz, will allow the development of systems offering greater safety features through high resolution and enhanced LPI.

Radar Band Utilization

AAMA supports the FCC Notice that the vehicle radar service should operate in exclusive bands until it is certain that sharing criteria can be developed and implemented and driver safety is not compromised. Vehicular radar devices are designed to provide warning/collision avoidance functions to enhance driver safety. The United States has one of the lowest fatality rates for vehicle usage of any country. The latest figures from the United States Department of Transportation National Highway Traffic Safety Administration show 1.7 fatalities per 100,000,000 miles driven for 1993. For comparison, the fatality rate for 1975 was 3.5 per 100,000,000 miles driven. Even with the current extremely low fatality rate, there were an estimated 33,420 vehicle occupant fatalities in 1993 according to the U.S. DOT.

AAMA recognizes that the electromagnetic spectrum is a resource that should be shared wherever possible. However, in the implementation of devices that build on existing safety systems, it is imperative that the current level of driver safety not be degraded.

The initial radar devices are expected to include items such as Intelligent Cruise Control which will offer the vehicle driver added comfort and convenience not available with today's cruise control systems. Other devices

are expected to add to the driver comfort and convenience as well as enhanced safety during normal vehicle operation. AAMA proposes that vehicle radar systems be the only devices operating in the specified bands until further information is gained concerning interference effects of other users of the electromagnetic spectrum. In this manner, an orderly, cost effective, scientifically based, approach can be developed to possibly expand these bands to other users.

Spectrum Auctions for Automotive Radar

2. We concur with the Commission that the expected general use of automotive radar systems for the public good negates auctioning these bands as they will not generate compensation from subscribers. The radar devices will benefit the public and the social good of the country will be enhanced.

Multiple Users in Bands

The FCC has requested comments regarding licensed, unlicensed, and government users for the millimeter bands described in the Notice. We refer to our comments and discussion provided in response to the Section on automotive radar bands. AAMA acknowledges efficient use of the electromagnetic spectrum and possible sharing of spectrum are goals that the Commission should strive to meet. Multiple applications in a band is common practice. AAMA members' products operate under Part 15 using this shared spectrum criteria for keyless entry, low tire pressure indicator, garage door opener, etc.

Vehicle radar systems are more than passive devices that provide operators with comfort or convenience type information. Vehicular radar systems will offer users comfort and convenience, but a future major focus for these devices is to enhance driver safety. These systems must operate in all

environments on public streets, throughout the United States and other countries. Furthermore, these radar systems must operate as a dynamic safety system while the vehicle is in motion. Therefore, the approach taken by the FCC of providing exclusive use to vehicular radar is the correct approach.

These safety systems need to be evaluated from the perspective of how many vehicle systems will interfere - or not - with one another, not only from self-interference from like radars but from cross-interference from other unlike radars. AAMA submits that due to the safety nature of vehicular radar systems, sufficient information be gathered to make an intelligent, scientifically correct decision regarding enhanced safety benefits before studying the potential effects of additional radiators on the same frequency bands. After vehicular radar systems have been introduced in sufficient numbers and data established, an appropriate mechanism should be developed to determine/establish test procedures and protocol for other devices that could be considered candidates for shared spectrum applications.

AAMA submits it may be necessary for branches of the Federal Government, in addition to the FCC, and professional societies to participate in the investigation of possible shared uses. Vehicular radar system performance standards may be established by several groups. These standards may encompass human factors issues such as type(s) of alert(s) allowed, minimum range for crash avoidance devices, operational conditions (e.g. ambient weather, temperature, humidity, etc.). With the advent of the Intermodal Surface Transportation Safety Act, the Federal Highway Administration may also become involved with roadside electronic devices to help implement the Intelligent Vehicle Highway Systems. Without proper coordination there is concern that some of the specifications set by the various agencies may conflict.

Secondly, it must be noted that the average vehicle life is approximately 10+ years. Therefore, the vehicle that is produced and put into commerce on the first day of its life, will be expected to operate in the environment for at least 10 years. During that 10 or more year time interval, it is anticipated technology will incorporate new methods using new waveforms and modulation techniques. Vehicle operators must be assured that if the bands are permitted to be used for other applications, there will be no adverse effects for those vehicles already in use.

AAMA Requested Power Levels For Automotive Radar Systems

AAMA's spectrum requirements were created based on three goals: 1) allow open entry to multiple systems, 2) promote development of current as well as future auto radar systems, and 3) avoid mandated design requirements. AAMA's intentions are to set forth performance requirements and not impose system design restrictions. By adhering to these goals, electromagnetic spectrum for automotive radar systems would be addressed via one NPRM, thereby avoiding multiple rulemakings by the FCC for each new application. This NPRM is expected to satisfy the domestic automobile manufacturers planned systems development.

Originally, power levels as submitted in February 1994 by AAMA, (Table 2.1 in AAMA's submission to FCC Docket RM-8308) were estimated based on information and knowledge in 1993. The proposed in-band power limits were larger than can be obtained by current technology. However, the AAMA goal was to not inhibit more advanced systems by setting too low of a power level. In 1994, AAMA reviewed the table and new maximum in-band values were proposed. The values shown in Table 3 are higher than power levels in known systems under development. Additional power is provided to allow for the development of advanced radar systems. Such advanced systems will

Table 3. Recommended Levels for Allowed Maximum Power Emissions

FREQUENCY BAND (GHz)	MAXIMUM AVERAGE FLUX DENSITY (mW/cm ²) ^a	MAXIMUM PEAK FLUX DENSITY (mW/cm ²) ^a	MAXIMUM IN-BAND & OUT-OF BAND SPURIOUS PEAK POWER (μW/cm ²) ^{a,b}
76 - 77	0.06	0.3	0.95
94.7 - 95.7	0.11	0.3	0.95
152 - 154	0.22	0.6	1.9

NOTES: a: Measured at 3 m from the emitting aperture within the main beam.

b: The lesser of the table value or 25 dB down from the main beam peak flux density.

The technical support for AAMA's comments are included in the body of the comments.

include features that are impossible to foresee today and will benefit from technology breakthroughs that cannot be predicted. For example, a typical maximum range for collision avoidance systems for applications under investigation today is typically stated as 100 meters by some researchers. However, collision warning systems developed in the future will require a maximum range of 150 meters to 300 meters based on vehicles moving at highway speeds to provide control/driver response time necessary to make corrections. Correspondingly, effective radiated power may need to increase above that used in 100 meter systems (typically 10 mW). This subject is discussed in more detail in the required power sections (Page 22).

AAMA has reviewed the suggested power density limits and believes from our analysis that higher powers are required. The $30 \mu\text{W}/\text{cm}^2$ power density at a range of three meters as proposed in the NPRM is too low to permit vehicular radar devices to operate at distances up to 300 meters. AAMA will show that the NPRM limits will mandate design restrictions thereby inhibiting current and future developments. The following is a discussion based on electromagnetic principles that provides a realistic compromise.

Bandwidth And Power Justification

AAMA has reviewed the power density limits, both in and out of band, presented in the Notice and has found the power density limit of $30 \mu\text{W}/\text{cm}^2$ measured at three meters to be insufficient for current and advanced automobile radar systems. Required operating power limits, all of which are requested for use by vehicular radar systems, are listed in Table 3. These operating limits will allow the development of both current and advanced systems while conforming to ANSI C95.1.

Additionally, AAMA has found the proposed FCC's power density limit outside the main lobe of $200 \text{ } \mu\text{W}/\text{cm}^2$ (22 dB down from $30 \text{ } \mu\text{W}/\text{cm}^2$) to be very limiting and costly. A typical first side lobe exists at about 15 dB down from the main lobe of the antennas being developed for automotive radar applications. Values of 17 and 18 dB down may be achievable for a high volume, low cost antenna. However, to obtain first side lobes of 22 dB down would require a sophisticated and expensive antenna design. Such a system would not be feasible for a low cost automotive radar design. AAMA recommends that any requirement for the first side lobe be specified as 15 dB down from the main lobe. We know of no reason or concern to want side lobes of 22 dB down.

The bandwidths as submitted in comments to the FCC in February 1994 (RM-8308, Table 2.1) were selected based on AAMA's evaluations regarding various system requirements, system inter and intra interference, and system cost. All of these items were reviewed with respect to the concept of open entry band utilization. The following revised table reflects AAMA's revised input to the notice for recommended power levels. Table 2.1 submitted in RM-8308 should be replaced with the following table which is based on refined analysis:

Table 3. Recommended Levels for Allowed Maximum Power Emissions

FREQUENCY BAND (GHz)	MAXIMUM AVERAGE FLUX DENSITY (mW/cm ²) ^a	MAXIMUM PEAK FLUX DENSITY (mW/cm ²) ^a	MAXIMUM IN-BAND & OUT-OF BAND SPURIOUS PEAK POWER (μW/cm ²) ^{a,b}
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NOTES: a: Measured at 3m from the emitting aperture within the main beam.

b: The lesser of the table value or 25 dB down from the main beam peak flux density.

Probability Of Interference

Radar warning systems must provide information to the driver with an extreme degree of reliability due to the safety-critical nature of the devices. Misinformation, as seen by the driver, could either be warning information of targets that are not present or no warning information when targets are present. These false alarms must be virtually zero to assure a safe, reliable system. Safe, reliable systems will assure marketable success through enhanced safety and usefulness.

A dominant source of false alarms is interference. Interference is generally caused by the following: 1) high power levels saturating the receiver, preventing the desired signals to be received, or; 2) an interfering signal from another like or unlike system

that is in-band of the receiver intermediate frequency (IF). Appropriate compression performance will need to be designed into the sensor front ends to handle saturation type of interference assuming the worse case condition of high density oncoming traffic and interfering transmitted peak powers listed in Table 3. Interference by competing signals is expected to be the predominant factor in false alarms.

Interference from unlike systems (cross-interference) essentially raises the receiver in-band noise floor, thus, reducing the receiver SNR. Interference between like systems (self-interference) has a more disruptive effect in generating false targets. However, depending on the signal processing algorithms used, both self and cross-interference may induce false alarms.

To achieve a virtual zero false alarm rate as experienced by the driver, spread spectrum waveforms are being utilized in the current developing systems. Spread spectrum techniques inherently produce a low probability of interference. The transmitter/receiver pair do not dwell (process) on the same frequency but rather process a band of frequencies over time. Both FMCW and frequency stepped systems are currently being developed. These waveforms form a natural "key" for the system reducing both self and cross-interference. The natural keying, however, requires the wider transmission bands.

A spread spectrum approach leads to low probability of interference (LPI). In considering allowable radiated powers, both receiver saturation and interference must be examined. In doing so, two portions of the receiver must be reviewed: (1) the RF, (wide band) portion, and (2) the IF (narrow band) portion. Prior to discussing the receiver, however, it must be understood that the power generated by another system will attenuate at $1/R^2$ and that the closest that any system can be to another system would be approximately eight meters. In practice, however, this eight meter range would occur infrequently and only for brief instances and would typically be much greater. Refer to Figure 3.

The RF portion of the receiver must be capable of receiving the wide band transmission, see Figure 4. Therefore, it is susceptible to another transmitter transmitting within the receiver RF wide band. The limiting factor for the RF band is the dynamic range of the receiver's RF. More specifically, the 1 dB compression point and noise figure of the RF mixer. Typically, a millimeter wave mixer 1 dB compression point is about 0 dBm. For an oncoming transmitter generating a peak signal of 40 mW (16.97 dBm) at a range of approximately 8 meters, a slightly less than 0 dBm peak signal would be seen at the receiver for only a brief moment in time. The opposing signal would not saturate a typical receiver. Rather than saturate the receiver, the opposing signal would be unwanted energy, possibly seen at a low noise amplifier (LNA). This could "blind" the receiver but, again, for less than a second, at highway speeds. The dynamic range of the LNA would, per good engineering design practice, be designed to accommodate the environment. Furthermore, the interfering signal at such short ranges would be momentary. Typically, the interfering ranges would be much larger. Saturation of the RF portion of the receiver would not be an issue.

More important is an interfering signal inside the narrow band IF filter. With spread spectrum systems, the IF bandwidth is much narrower than the transmitting bandwidth. Thus, only a small portion of the wide band transmitted signal (the instantaneous transmitted signal) passes through the narrow band IF filter for some particular time duration. To illustrate the effect of receiving IF in-band unwanted energy, take the example of two opposing spread spectrum systems, see Figure 4. For simplification, let both systems operate over the same transmit bandwidth and be frequency stepped, to quantize the problem. Assume the receiver bandwidth and step rates are equal. With both systems stepping in different sequence, it can be shown that the probability of both systems transmitting, thus receiving, the same instantaneous frequency is less than 0.2%. Therefore, for more than 99.8% of the